Part I. *Pioneer* Project and *Pioneer VI* Mission

I. Introduction

A. Objectives

Pioneer VI was the first in a second generation of unmanned spacecraft launched by the *Pioneer* Project under NASA control to collect data on interplanetary phenomena. The *Pioneer* Project was designed to provide a means to study the magnetic field, spatial plasma, cosmic rays, high-energy particles, electron density, electric fields, and cosmic dust within a region of 0.75 to 1.20 astronomical units (AU) from the sun. Data was analyzed to obtain knowledge of solar disturbances and the relationship between solar and galactic fields. The Project was initiated in 1958 as part of U.S. participation in the International Geophysical Year. Near-real-time data reduction and analysis was a part of a *Pioneer* space weather report teletyped regularly to U.S. Space Disturbance Forecast Centers.

Pioneer V, in closing out the first *Pioneer* generation, remained active in space more than 3 mo and was not lost to earth contact until it was 27.5 million km from earth. This was a new record.

Pioneer VI was launched December 16, 1965, on an inward trajectory to heliocentric orbit, perehelion near 0.80, and aphelion near 0.98. (The launch vehicle was a thrust-augmented improved *Delta* or DSV-35.) Completing the near-earth phase on launch day, the spacecraft was successfully tracked by the 85-ft-diam antenna stations of the Deep Space Network (DSN) until June 29, 1966. The *Pioneer VI* spacecraft was then officially acquired by the DSN's only 210-ft-diam antenna station for what was designated an "extended flight" phase.

Before launch, the life expectancy for *Pioneer VI* spacecraft was estimated to be 6 to 8 mo. Later, the estimate was changed to 5 yr or more, with the capability of the completed 210-ft-diam antenna at Mars station (DSS 14), Goldstone, Calif. Improvements also increased the capabilities of the 85-ft-diam antenna stations. The spacecraft was expected to return to satisfactory contact

Table 1. DSN station designations and locations

Location	Station number	Geodetic latitude	Geodetic longitude	Height above mean sea level, m	Geocentric latitude	Geocentric longitude	Geocentric radius, km
Goldstone, Calif. (Pioneer)	11	35.38950°N	243.15175°E	1037.5	35.20805°N	243.15080°E	6372.0341
Goldstone, Calif. (Echo)	12	35.29986°N	243.19539°E	989.5	35.11861°N	243.19445°E	6372.0176
Goldstone, Calif. (Venus)	13	35.24772°N	243.20599°E	1213.5	35.06662°N	243.20507°E	6372.2599
Goldstone, Calif. (Mars)	14	35.42528°N	243.12222°E	1160	35.24376°N	243.12127°E	6372.1341
Woomera, Australia	41	31.38314°S	136.88614°E	144.8	31.21236°S	136.88614°E	6372.5317
Tidbinbilla,[a] Australia	42	35.40111°S	148.98027°E	654	35.21962°S	148.98027°E	6371.6686
Johannesburg, South Africa	51	25.88921°S	27.68570°E	1398.1	25.73876°S	27.68558°E	6375.5415
Madrid, Spain (Robledo)	61	40.429°N	355.751°E	800	40.238°N	355.751°E	6370.0868
Cerebros, Spain	62	—	—	—	—	—	—
Cape Kennedy, Fla.	71	28.48713°N	279.42315°E	4.0	28.32648°N	279.42315°E	6373.2913
Ascension Island[b]	72	7.95474°S	345.67242°E	526.7	7.89991°S	345.67362°E	6378.2386

[a]Formerly listed as Canberra.

[b]No longer operated by DSN.

with the DSN's 85-ft-diam antenna stations during the second half of 1970. (*Pioneer VI* support by the DSN was to be terminated if the telemetry bit error rate reached an unacceptable level.)

This document reports the first three years of extended flight phase support in annual increments. Table 1 lists the DSN stations and locations during the period reported.

B. Tracking and Data Acquisition Support

The Tracking and Data System (TDS) began support of *Pioneer VI* during the near-earth phase (launch until deep space station two-way lock with the spacecraft) by tracking the spacecraft. It thereby acquired launch vehicle and spacecraft telemetry data (generating metric data through C-band radar tracking of the transponder on the launch vehicle and S-band radio tracking of the transponder on the spacecraft) and also transmitted commands to the spacecraft.

The TDS was made up of the Air Force Eastern Test Range (AFETR), Manned Space Flight Network (MSFN), NASA Communications System (NASCOM), and the DSN. This report is concerned with the activities of the DSN, which was under management and technical direction of the Jet Propulsion Laboratory, California Institute of Technology. Ames Research Center (ARC) was the manager of the *Pioneer* Project.

1. DSN configurations. The DSN had the capability for two-way communication with spacecraft travelling as near as 10,000 miles from earth and as far as interplanetary distances. Facilities of the DSN were the Deep Space Instrumentation Facility (DSIF) for data acquisition and transmission, the Ground Communications Facility (GCF) for data transfer, and the Space Flight Operations Facility (SFOF) for data processing. DSN systems were tracking, telemetry, command, simulation, monitoring, and operations control. Figure 1 diagrams the DSN and *Pioneer* Project systems. Figure 2 is a DSN facility-system matrix.

The 85-ft-diam antenna stations that supported the *Pioneer VI* spacecraft in the deep space flight phase were Pioneer (DSS 11) and Echo (DSS 12), both at Goldstone, Calif., Woomera (DSS 41) and Tidbinbilla (DSS 42), in Australia, Johannesburg (DSS 51), in South Africa, and Robledo (DSS 61), Madrid, Spain. The DSN objectives were:

(1) Acquire spacecraft engineering and science data via telemetry.

(2) Provide for positive control of spacecraft.

(3) Provide for accurate spacecraft navigation by generating radio metric data.

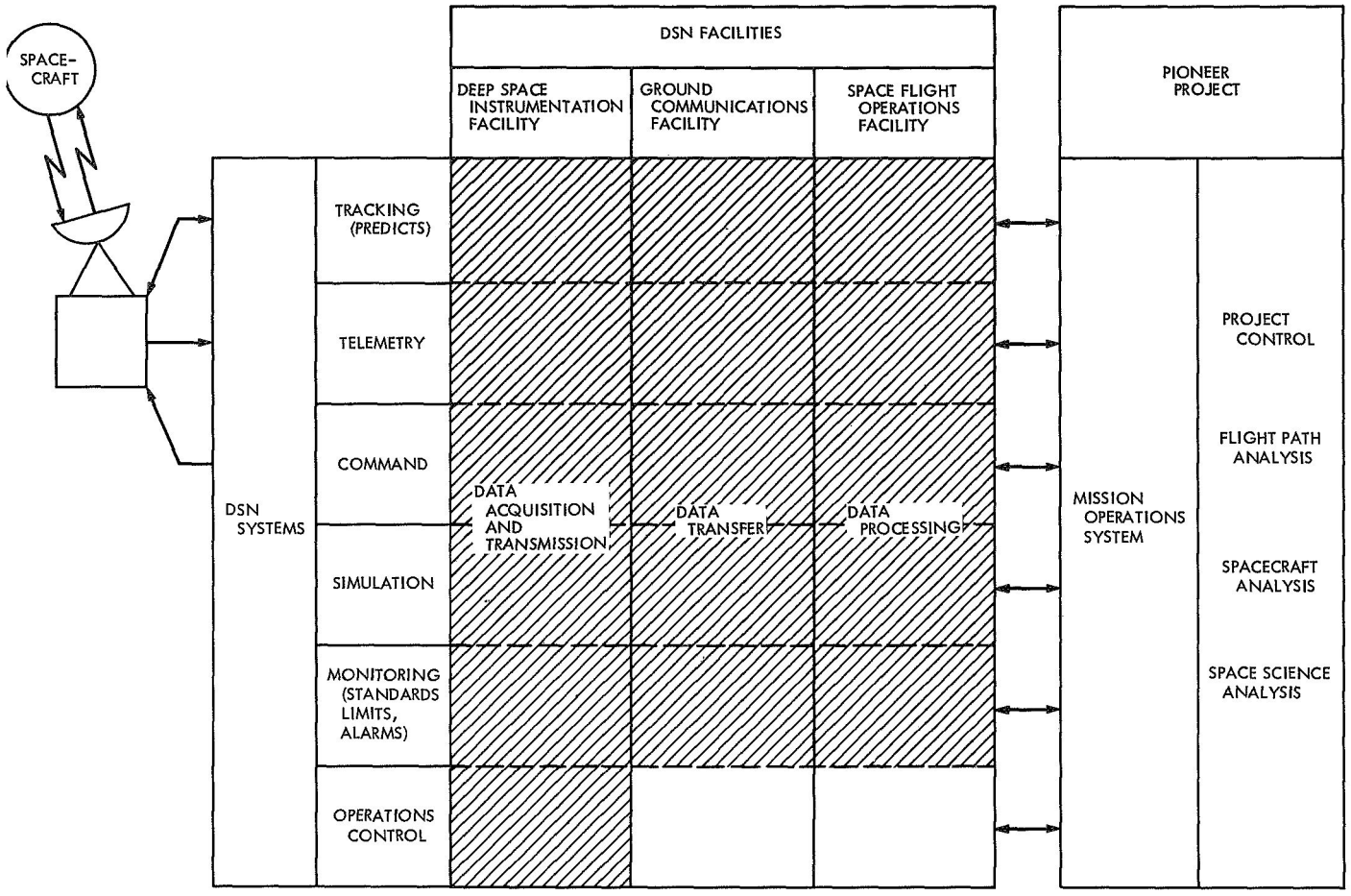

Fig. 1. DSN and *Pioneer* Project systems diagram

(4) Provide support for a number of complex missions concurrently.

(5) Provide master data records of validated data in near-real-time.

The DSN was capable of providing 24-h coverage for spacecraft. This requirement was important for flexibility in planning missions and providing maximum data return and also for immediate detection of spacecraft failure and initiation of recovery procedures. If mission density required two such 24-h-coverage networks, then the alternate network provided coverage for a station outage. Station locations were approximately 120 deg apart in longitude and within a band of 35 deg latitude on each side of the equator. This provided continuous coverage of spacecraft in the ecliptic plane in most cases.

The amount of data processing or data compression activity at tracking stations depended greatly on the bandwidth, signal-to-noise quality, and reliability of the ground interstation communications network. The characteristics of ground communications facilities dictated that data processing and compression be available

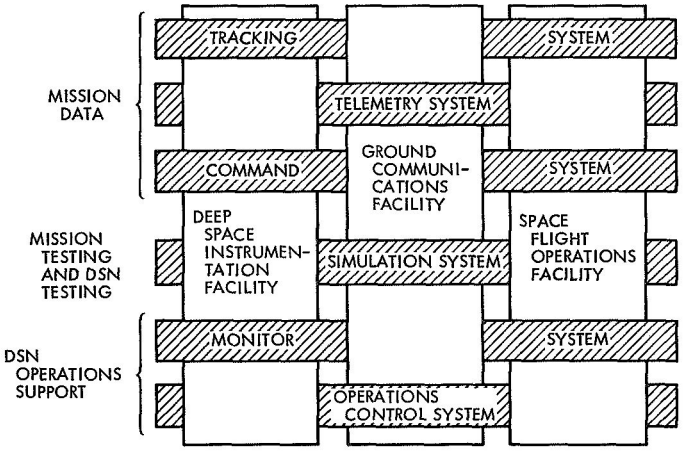

Fig. 2. DSN facility, system matrix

at tracking stations. Ideally, in the interests of simplifying the deep space station design and reducing station costs, it was desirable to transmit the baseband data directly from the receiver to a central facility, where the data would be detected and/or formatted for local use. This required a reliable, continuously available, wideband (<2 MHz) duplex channel between the control center and each station. The situation required that a certain amount of data processing and compression for tracking data formatting, telemetry bit and word detection, and command formatting be used at the stations. The ground communication system could make use of a common carrier to convey this material to the stations, but it was more economical, when standard communication circuits were required for several networks, to have a centralized agency; NASCOM (National Aeronautics and Space Administration Communication Network) provided this service. Such centralized service provided high-speed data lines (2400 bits/s), voice, limited wideband lines, and teletypewriter circuits via ground or communications satellite facilities.

The control center (SFOF) provided a central processing system and areas dedicated to several spacecraft mission control operations. The control center also provided the control function for operation of the space communication stations, ground communication facilities, and the control center itself.

2. Pioneer design concepts. The *Pioneer* data system was developed to provide (1) a highly efficient telemetry channel compatible with the DSN, (2) a capability for the DSN to generate two-way coherent doppler measurements while the spacecraft was tracked, and (3) an earth-to-spacecraft command capability to control the spacecraft subsystems and science payload.

a. Spacecraft radio frequency subsystem. The radio frequency subsystem included three antennas (one high-gain and two omnidirectional), a transmitter driver, two redundant traveling-wave-tube (TWT) power amplifiers, two redundant receivers, coaxial switches, filters, and diplexers. Switch position was controlled by ground command. The beam of each of the antennas was axially symmetrical with the spacecraft spin axis, which was perpendicular to the ecliptic plane. The beamwidth of the omnidirectional, or low-gain, antenna was 110 deg, and the beamwidth of the high-gain antenna was 5 deg.

The power output of the spacecraft transmitter exciter was 44 W and could be switched by ground command to the low-gain antenna or used as a driver for the two TWT power amplifiers. Each amplifier had a power output of approximately 7.7 W and could be turned on or off or switched to either the low- or the high-gain antenna by ground command. The auxiliary oscillator was modulated by a 2048-Hz squarewave subcarrier as part of a PCM/PSK/PM telemetry system.

The spacecraft had two partially redundant (redundancy limited by the antenna configurations) phase-lock receivers. Each operated on a different frequency and was powered at all times; the desired receiver was thus selected by the frequency of the ground transmitter.

b. Spacecraft command subsystem. The command subsystem consisted of two redundant decoders and a command distribution unit (CDU). The input signal to both decoders was the demodulated signal from either of the spacecraft receivers. The desired decoder was selected by command address.

The command message was a 23-bit word arranged in the following order:

5 bits, preamble.

3 bits, decoder address.

7 bits, command complement.

7 bits, command.

1 bit, post-squelch.

The command and command complement were compared within the decoder on a bit-by-bit basis, and the command-execute signal from the decoder was inhibited when errors occurred. The ones and zeros within the message were represented by two audio tones. The command carrier was phase-modulated by these tones at the rate of 1 bit/s.

c. Spacecraft telemetry subsystem. The generation of timing and status signals, analog-to-digital conversion, data retrieval and processing for telemetry, and data storage on the spacecraft was accomplished by the digital telemetry unit (DTU), the signal conditioner, and the data storage unit (DSU).

The output of the DTU was a 2048-Hz squarewave which was biphase-modulated with the time-multiplexed PCM bit train using a non-return-to-zero-mark format. This squarewave phase-modulated the transmitted carrier in all modes of operation.

The DSU had a capacity of 15,232 bits. Readout from the memory unit was destructive and, once initiated, could not be temporarily interrupted by ground command without destroying the remaining data in the unit. Furthermore, the unit had to be cleared of any data stored there, either by ground command or by readout of stored data, before a new storage cycle was begun.

By ground command, one of four operating modes and one of five bit rates could be selected for operation of the DTU. The operating modes were (1) real-time, (2) telemetry store, (3) duty cycle store, and (4) memory readout. The bit rates were 512, 256, 64, 16, and 8 bits/s.

Data quality for *Pioneer VI* was determined by the error-rate printout on the engineering data. In addition, Ames Research Center kept plots of error-rate printout values. An error-rate printout of 0.116 corresponded to one error in 1000 bits of information and was used as a criterion for good data. (If the parity error rate was not less than this value, the bit rate was dropped to the next lower value.) Primary interest was in data for the time interval beginning 3 h prior to the time of maximum spacecraft elevation and extending until 3 h after. Some passes terminated more than 3 h before the spacecraft reached maximum elevation, and parity error rates were calculated from such data as was available.

Varying amounts of data were lost or degraded in locking the receiver in a two-way mode on each pass; the amount varied because of the round-trip light time (RTLT), which increased as the spacecraft's distance from earth increased. Spacecraft acquisition time also contributed a small portion of lost or bad (degraded) metric data. Receiver-lock was essential for good data recovery.

In the real-time mode, the information was transmitted directly in the format and bit rate selected. In the telemetry-store mode, data was stored and transmitted simultaneously in the selected format and bit rate. In the duty-cycle-store mode, data was stored intermittently in groups of 224 bits each at a rate of 512 bits/s. The period between groups stored could be selected by ground command to provide partial data coverage for periods up to 19 h. The memory-readout mode provided the capability for retrieving the data stored. When readout was complete, the DTU reverted automatically to the real-time mode in the format and at the bit rate in use prior to the readout.

The spacecraft data word was composed of 7 bits. The first 6 bits transmitted were generally information and the seventh indicated parity. Odd parity was employed by sampling the first, third, and fifth bits.

d. Mission-dependent ground equipment. This equipment consisted of a demodulator/synchronizer, a command encoder, and a computer buffer. A DSN computer was used at the station to:

(1) Provide selected telemetry data for teletype transmission to the SFOF.

(2) Monitor the engineering data for out-of-limit occurrences.

(3) Provide computer typewriter printout of selected data.

(4) Display selected spacecraft parameters as required.

(5) Transmit command messages on instructions from the SFOF.

(6) Check command messages for validity before transmission.

(7) Verify that commands were being transmitted correctly.

(8) Maintain a command accountability list.

The complete data stream was recorded on magnetic tape for subsequent data processing and analysis.

3. *Extended flight phase support requirements.* Almost from launch of the *Pioneer VI* spacecraft, mission requirements for TDS support increased. Changes resulted, in the main, from the spacecraft's increased life expectation, and the added possibilities from an extension of reach by the DSN.

a. Guidelines. Mars station (DSS 14), which was not yet operable at launch, was made available on a best-effort basis for *Pioneer VI*. However, the support Instrumentation Requirements Document (SIRD) and the NASA Support Plan (NSP) for *Pioneers VI, VII,* and *C* were completed in 1967. Looking ahead to extended phase coverage of *Pioneer VII*, which had been launched in August 1966, and spacecraft of outside projects, the NSP adjusted the early support commitment. The new

guidelines called for the Mars station to furnish a minimum of 180 h per month for tracking and data acquisition support for *Pioneer* spacecraft. This minimum tracking time was to be increased whenever possible. (Requirement revisions were made on a periodic basis.)

b. Early Operation. Regular acquisition of *Pioneer VI* by DSS 14, with the Goldstone Echo station (DSS 12) and the microwave link, officially took place June 29, 1966. At that time the 210-ft-diam antenna was used for downlink only; the 10-kW transmitter at Echo was used for uplink. To conduct command and real-time data transmission activities, the microwave link was used between the Mars and Echo stations. Last acquisition of *Pioneer VI* by Echo was July 13, 1966. (Previous to use for *Pioneer VI*, DSS 14 had its first operational use in support of the *Mariner* Mars 1964 mission solar occultation experiment in March of 1966. Only the station receive capability, augmented with R&D equipment, was used. As the station's capabilities had become available during construction, they were verified through use of the *Mariner IV* spacecraft S-band telecommunications system.)

c. Restrictions. Because the Mars station was the only facility with the 210-ft-diam antenna, required hardware modification and testing at the station sometimes interrupted regular tracking operations. (DSN plans called for construction of two additional 210-ft-diam antenna stations: one in Australia and one in Spain.)

4. Advanced antenna system facility description. The 210-ft-diam advanced antenna system (AAS) at Goldstone, Calif. (Fig. 3), increased the DSN range two and a half times. Under limited communications conditions, the system reached to the edge of the solar system. The improved capability provided six and a half times more transmitting power and receiving sensitivity for the DSN than was available with 85-ft-diam antennas. The 210-ft antenna had a gain of approximately 60 dB in transmitting and 62 dB in receiving. The 85-ft antennas had a gain of 51 dB transmitting and 53 dB receiving. The beamwidth was 0.1 deg at Mars and 0.35 deg for 85-ft antennas.

The added capability permitted either extension of communication distances in space or acquisition of more data from spacecraft at shorter ranges. Because the new station located more of the complex equipment on the ground, less complex and more reliable communication equipment could be carried by spacecraft. The 210-ft antenna, a parabolic reflector with an azimuth-elevation mount, had a specified lifetime of 10 yr and an expected lifetime of 20 to 50 yr. It was capable of operation 24 h a day, 365 days a year.

The operating and signal-processing techniques used for the 210-ft antenna were basically the same as those used for the 85-ft antennas. The huge reflector was tuned to collect spacecraft signals coming from such distances that their energy was measured in billionths of a billionth of a watt. These signals were amplified and fed into receivers, and the data forwarded to the SFOF in Pasadena.

Tracking of the spacecraft began as it appeared above the horizon. Frequency, time, and angle data of the predicted trajectory was supplied by teletype from the SFOF and other DSN stations. Signal acquisition and lock-on were normally achieved in 4 to 10 min. The antenna was then switched to the automatic mode and tracked until the spacecraft disappeared below the horizon.

The 210-ft antenna operated in either of two pointing modes, depending on the nature of the mission being covered. It was pointed so as to track the spacecraft signal automatically, as did the 85-ft antennas, or the pointing information was sent to the 210-ft antenna master equatorial reference system, which then designated the path for the antenna.

Like other DSN antennas operated at frequencies of 2100 MHz transmitting and 2300 MHz receiving, the DSS 14 antenna incorporated a Cassegrain cone feed, mounted at the center of the reflector. (During March of 1968, an ultracone was installed. This improved the downlink signal strength by some 5 dBmW for one-way tracking.) The Cassegrain design was similar to that of an optical telescope. Signals reflected from the main dish hit a subreflector mounted on a truss-type support extending outward from the center of the dish. The subreflector focused the signal into the feed horn in the Cassegrain cone, where it was amplified by a maser.

The maser was capable of accomplishing maximum amplification of the signal while, at the same time, generating a minimum of background noise. Because heat was a major source of noise, the maser was immersed in liquid helium to maintain its temperature at 4.2°K. The

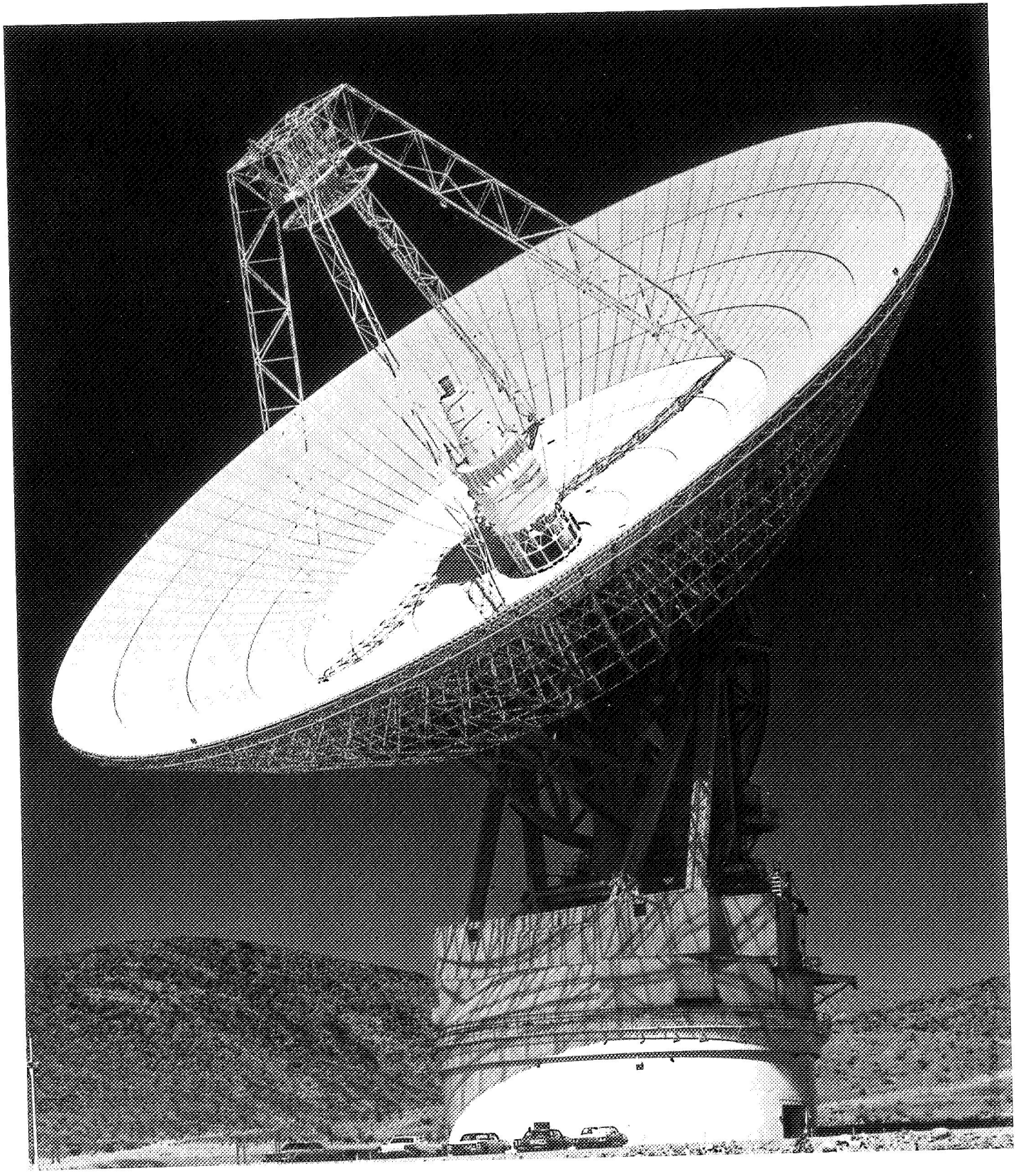

Fig. 3. View of 210-ft-diam antenna

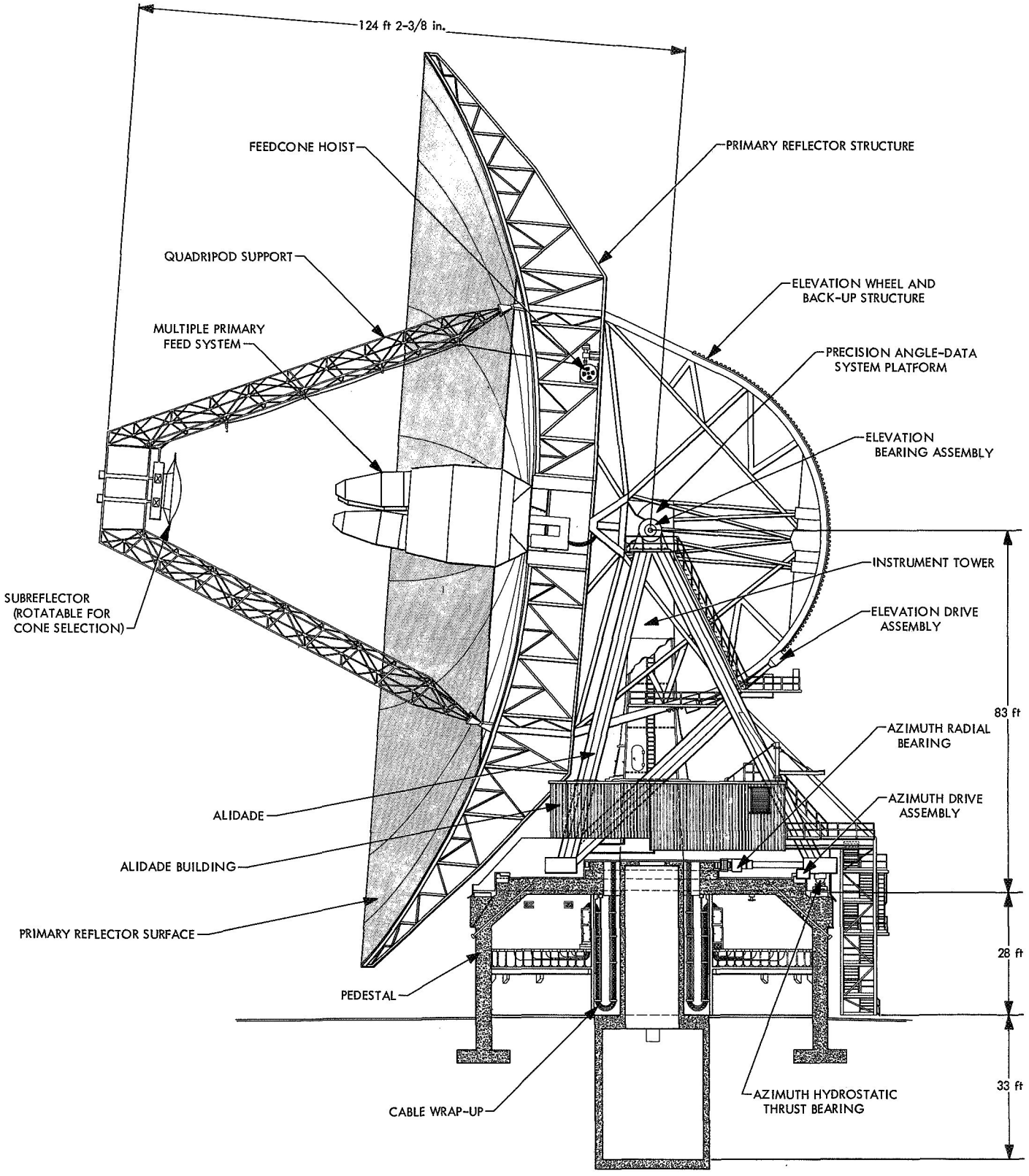

Fig. 4. Profile of 210-ft-diam antenna

Table 2. Antenna dimensions and weights

Antenna dimensions	
Diameter, ft	210
Focal length, ft	88.941
Focal length/diameter ratio	0.4235
Surface area, ft^2	37,491 (0.85 acre)
Depth of paraboloid, ft	31
Pedestal wall thickness, ft	3.5
Outside diameter of pedestal, ft	83
Overall height of instrument tower,[a] ft	139
Total concrete, yd^3	2500
Antenna weights, lb	
Overall	16,000,000
On elevation bearings	2,530,000
On azimuth bearings (including bearings)	5,000,000
On soil	16,000,000
Total rotating	5,000,000
Total tipping	2,500,000
Component	
Hyperboloid	4,100
Feed cone and equipment	62,000
Quadripod	39,000
Primary reflector surface	58,000
Reflector assembly (including reflector, wheels, and elevation counterweight)	2,370,000
Alidade and buildings	2,200,000
Azimuth bearings	400,000
Pedestal and foundation	10,000,000
Instrument tower (including wind shield)	
Steel	96,000
Concrete	1,151,000

[a]Height of concrete section, 68 ft, including 33 ft below grade.

spacecraft signal was usually maser-amplified on the order of 40,000 times before it was fed into the receiver, where it was further amplified.

The receiver used four separate channels: two reference (or sum) channels for doppler information, spacecraft telemetry, and TV signals, and two channels carrying angle-tracking data for automatic antenna pointing. The data from all four channels, depending on the information they conveyed, was transmitted to the SFOF.

Dimensions and weights of the 210-ft antenna are given in Table 2. A profile of the antenna is presented in Fig. 4.

II. Scientific Events and Measurements

A. Special Coverage

Special coverage was given *Pioneer* spacecraft during occultations and syzygys; analyses of solar events were made, and investigations were made of magnetosheath and bow shock. During a solar event of high scientific value, continuous tracking coverage for 30 to 50 h following the event was required for *Pioneer* spacecraft. Dependent upon the location and characteristics of a specific event, coverage was shared by the *Pioneers* as determined by the *Pioneer* Project at the time of the event. For magnetosheath and bow shock, on-board plasma and magnetometer instruments needed to be operating and the resultant scientific data received by launch plus 3 to 3½ h or 8 to 10 earth radii altitude.

Continuous tracking during a 1-mo period was required for *Pioneer VI* to cover solar occultation (November 21 through November 24, 1968). An analysis of the solar corona and atmosphere near the solar disk as the spacecraft occulted was desired.

Pioneer VI carried six scientific instruments, which totalled 34.1 lb or 25% of the total spacecraft weight. Nine W of power was required for the instruments when one plasma detector was operating in low-power mode and 18 W when in the high-power mode (approximately 18 and 35% of the total spacecraft power).

The instruments covered approximately 280 $in.^2$ of the spacecraft platform. Approximately 72% of the telemetry data was allocated directly to the scientific instruments when telemetering in the scientific data mode. This mode was used throughout the mission except for rare occasions. Approximately 33% of the command capability was allocated directly to the scientific instruments for controlling the operating conditions.

Power to the scientific instruments was supplied directly from the spacecraft primary bus. Each instrument, therefore, had its own converter. Power to all instruments was turned off by a single ground command. Each instrument could be turned on individually by ground

command. One scientific experiment, the celestial mechanics investigation, required no special instruments on the spacecraft. However, funding for this investigation was not available until the 1968 fiscal year.

B. Experiments

The experiments, managers, and principal investigators are listed in Table 3.

1. Celestial mechanics investigation (JPL). The three primary objectives of the *Pioneer* celestial mechanics experiment (PCME) were:

(1) Obtain primary determinations of the masses of the earth and moon and the astronomical unit.

(2) Use the tracking data from the whole series of *Pioneer* probes in a program designed to improve the ephemeris of the earth.

(3) Investigate the possibility of a test of general relativistic mechanics with the *Pioneer* orbits.

The experiment made use of the on-board receiver and transmitter equipment in conjunction with DSS equipment to obtain two-way doppler measurements. *Pioneer* data was appropriate for this experiment because of the absence of midcourse orbit corrections and near-planetary encounters. In addition, solar-radiation pressure effects were slight for the *Pioneer* configuration.

2. Cosmic ray telescope (University of Chicago). The intensity and energy spectra of protons and alpha particles, and electron energy over a limited range, as well as particle anisotropy, were measured by this instrument. It had three solid-state lithium-drift detectors, a plastic scintillator cylinder designed to exclude particles not confined to the telescope angle of 60 deg, a photomultiplier tube, and associated electronics. Proton and alpha particle energy spectra measurement was divided into these four energy windows: (1) 0.6–13 MeV per nucleon; (2) 13–70 MeV per nucleon; (3) 70–190 MeV per nucleon; and (4) greater than 190 MeV per nucleon. Detection of electron energy spectra was limited to the energy windows of 0.16–1 and 1–20 MeV per nucleon.

3. Cosmic ray anistropy detector (Southwest Center for Advanced Studies). Measured were the anistropy of low-energy primary and solar cosmic radiation and its variation with energy, time, and nuclear species. The instrument comprised a scintillator crystal, an anticoincidence scintillator, two photomultiplier tubes, and associated electronics. The acceptance cone for the detector was 107 deg. Energy window discrimination was achieved by means of a four-channel, on-board, pulse-height analyzer.

Table 3. *Pioneer VI* experiments

Experiment/scientific instrument	Management	Principal investigator
Single-axis magnetometer	NASA/GSFC	N. Ness
Plasma cup detector	MIT	H. Bridge
Quadrispherical plasma analyzer	NASA/ARC	John H. Wolfe
Radio propagation detector	Stanford University	V. R. Eshleman
Cosmic ray anisotropy detector	Southwest Center for Advanced Studies	Kenneth McCracken
Cosmic ray telescope	University of Chicago	J. Simpson
Celestial mechanics investigation[a]	JPL	John D. Anderson
Solar occultation investigation only (10/20/68–12/6/68)		
Faraday rotation investigation (S-band)	JPL	Gerald S. Levy
Spectral broadening investigation (S-band)	JPL	R. Goldstein
Relativity investigation	JPL	John D. Anderson Leonard Efron

[a]Requires no on-board instrumentation; uses two-way doppler tracking as data source.

4. Plasma cup detector (Massachusetts Institute of Technology). A detector that used a Faraday cup with an energy-determining grid, a split collector, and associated electronics made up this instrument. The viewing angle was ± 20 deg in the plane perpendicular to the spacecraft spin axis and ± 60 deg in the plane parallel to the spin axis. Measured were the energy spectrum, flux, and angular distribution of both positive ions and electrons of the interplanetary plasma.

The energy per unit charge of the positive ions was determined in 14 intervals extending from 0.1 to 9.5 kV; the energy of the electrons in four energy bands extending from 0.1 to 1.6 keV, and the flux sensitivity range from 2×10^5 to 2×10^9 particles per cm^2/s.

5. Quadrispherical plasma analyses (Ames Research Center). This instrument, like the plasma cup detector,

measured the energy spectrum, flux, and angular distribution of both positive ions and electrons of the interplanetary plasma. The instantaneous viewing angle was approximately 15 deg in the plane perpendicular to the spacecraft spin axis or equatorial plane and ±80 deg in the plane parallel to the spin axis. The latter was divided into eight channels symmetrical about the equatorial plane and with widths, starting at the equatorial plane, of 15, 15, 20, and 30 deg.

The energy per unit charge of the positive ions was determined in 16 logarithmically spaced bands extending from 0.2 to 10 kV; the energy of the electrons in 8 logarithmically spaced bands extending from 0.002 to 0.5 kV; and the flux sensitivity from 10^5 to 10^9 particles per cm^2/s.

Besides a quadrispherical electrostatic analyzer, 8 separate and contiguous current collectors provided 8 sectors and associated electronics. The current or flux measurement was expressed as a 7-bit word and, together with other information identifying energy levels, positive or negative particles, collector, and equatorial interval, was stored in a core memory. The instrument recorded data concurrently with telemetering data.

6. Magnetometer (Goddard Space Flight Center). The magnetometer, with a range of ±64γ, sequentially measured the magnitude of the three orthogonal components of the interplanetary magnetic field. Capable of four different data recording sequences, the instrument had a single flux gate sensor and associated electronics. A mechanical flip mechanism, which rotated the sensor through 180 deg, permitted detection and elimination of permanent magnetization of the core. The flip mechanism contained 22 small squibs grouped in pairs for redundancy. Each pair of squibs was activated by ground command.

7. Radio propagation (Stanford University). This experiment involved the transmission of two modulated coherent carriers of approximately 49.8 and 423.3 MHz from the ground and the reception of these signals by receivers aboard the spacecraft. The receivers were designed to measure the relative phase of the modulation envelopes of the two carrier frequencies which, since the higher frequency was relatively unaffected by the presence of ionization, provided a value for the integrated electron density. In addition, the rate of change of phase of one carrier with respect to the other was measured, thus accurately determining the time variation of the integrated electron density. Signal strength was also measured.

Instrumentation comprised two ground-based transmitters operating into a 150-ft-diam parabolic antenna located on the Stanford University campus, a dual-channel, phase-locked-loop receiver aboard the spacecraft, the spacecraft telemetry, and the DSN. All elements of the system operated simultaneously to provide closed loop operation.

The experiment was terminated July 13, 1966, when the Stanford radio propagation instrument onboard the *Pioneer VI* spacecraft ceased to transmit useful scientific data. The spacecraft communication distance and the Stanford on-board receiver sensitivity threshold combined to end the acquisition of useful data. The need for JPL to produce Stanford predicts in support of the mission ceased with the end of the experiment.